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DEPLOYMENT OF MICROGRIDS IN THE DEVELOPED COUNTRIES: AN APPRAISAL

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ABSTRACT

Microgrids are the significant emerging systems for incorporating distributed energy generation into the larger electrical distribution system both from renewable as well as fossil fuel power sources. In the past decade the majority of microgrids had been only as pilot projects or research-related experiments, but such is not going to be the case in near future since whole power system is growing smarter very fast specially in the developed countries. Recent years have indicated a shift as some of the first commercial-scale microgrid projects reached noticable milestones. The budge from pilot corroboration projects to fully commercial projects is accelerating with the passable adoption of the IEEE islanding standards for microgrids. There is no particularly accepted benchmark test system for microgrids; as per the local necessitate different systems employ diverse microgrid topologies. This paper presents a detail appraisal of the current research development, demonstration and implementation work being carried out in the highly developed countries where the Microgrids are functional fruitfully; specifically at United States, Canada in North America and at Germany, Italy, United Kingdom in Europe. In this paper we shall see the implementation technical details, operating concepts, practical challenges and the control schemes of various microgrid set ups in the mentioned advance countries steering towards the wider goal of evolution of smart grid.

KEYWORDS: MicroGrid Configurations, Micro Grid Implementations, MicroGrid Projects, Developed Countries

INTRODUCTION

In a wide and futuristic manner, microgrids (MGs) are minuscule powers systems which embed various Distributed Generation units, Storage devices, local loads operating together in a harmonized manner with integrated power electronic controllers and protective devices [1]. Specifically the Micro grids comprise low voltage LV distribution systems with integration of Diverse Renewable Energy Resources mainly such as photovoltaic, wind, bio-mass, bio fuel and fuel cell together with Distributed storage like flywheels, energy capacitors and batteries and Controllable Loads that behave as a coordinated entity networked by employing advanced power electronic conversion and control capabilities [2]. A microgrid can be a DC, AC or even a high frequency AC grid. It can be a single or a three phase system or it may be connected to low voltage or medium power distribution networks. Furthermore, a microgrid could be operating in either grid connected or islanded operation mode. For each operating mode operational requirements are different and distinct control schemes are required. The leading edge feature of a microgrid is its ability to operate autonomously when there is a power outage in the main grid. This operation mode is called islanded operation since the microgrid disconnects from the grid and becomes an island with local generators and loads. In this way, the consumers may receive continuous service even when there is power outage in the grid due to a fault or maintenance. In this way, microgrids not only help in providing uninterrupted service but also contribute to the maintaining service quality. These microgrids may either be operated in concurrence with or islanded from the utility power grid and are exploited in a variety of situations like utility deployments, community utilization, military installations, commercial applications, institutional power systems, remote

villages' electrification etc. To accurately test and monitor the micro-grid systems' performance, a multifunction laboratory is needed that integrates generation, storage, loads, as well as electrical and thermal capabilities. [3].

MICROGRID PROJECTS ACROSS THE GLOBE

In the recent years Microgrids, being the core element of the smart grid evolution, has been an area under hot discussion. According to a new tracker report more than 160 microgrid projects are currently active around the world, with power generation capacity totalling more than 1.2 gigawatts. Across the globe several microgrid projects have been productively implemented in the advanced countries and few are in progress in the developing countries too. The process is expected to take a good pace with more emphasis on the smart grid to be factual. To mention there are a number of active Microgrid projects around the world namely in North America, European Union and South & East Asia involved in realizing the improved operation of microgrids, testing and evaluation of microgrid demonstration systems in a better sense. Looking across the globe it is found that North America remains the foremost region for microgrid deployments, representing 69% of total installed capacity. Asia Pacific and Europe are also the promising regions, with 19% and 12% shares of total capacity, respectively. [4]. Insistent smart grid deployment, emission reduction, and renewable source targets are fuelling the demand for these technologies in both Europe and North America.

This paper is an endeavour to present the state of art of research, development, and demonstration (RD&D) efforts concerning microgrids in the advanced countries. The numerous microgrid active implementations around the world cover a complete assortment of technologies. We shall attempt to appraise various microgrid topologies, set up specifications, operational configurations, their associated monitoring and control methodologies. Since the microgrid concept is very versatile, the experiment conditions and the objectives have a very wide span. Different technologies, topologies and operating modalities have been planned, employed and executed for different purposes as per the local requisites.

Microgrid Implementation in Ohio, United States

The pioneer and the most well-known U.S. microgrid RD&D effort established in 1999 has been pursued under the Consortium for Electric Reliability Technology Solutions (CERTS). The CERTS microgrid was constructed at a site owned and operated by American Electric Power, AEP near Columbus, Ohio. This test-bed shown in Figure 1 is a 480-volt system, connected to the 13.8kv distribution-voltage system through a transformer at the Point of Common Coupling. It has two main components autonomous DG sources and thyristor based static switches [5].

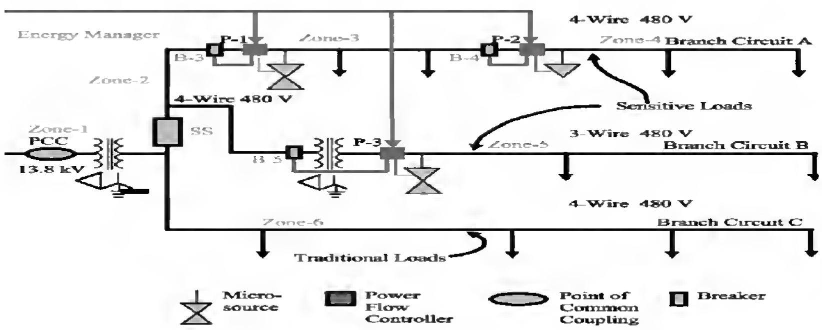

Figure 1: CERTS Microgrid Test-Bed [5]

The test-bed has three feeders, two of which have converter based DG units driven by natural gas. One feeder has two 60-kW sources and another feeder has one 60 kw source which can be connected and can be islanded. The third feeder

stays connected to the utility but can receive power from the micro sources when the static switch is closed without injecting power into the utility. Two feeder branch circuits consist of sensitive loads and the third branch circuit has traditional non-sensitive loads. Each source is connected in a peer-to-peer fashion with a localized control scheme implemented with each component. This arrangement increases the reliability of the system in comparison to a master–slave or centralized control scheme.

The objective of the testing is to demonstrate the system dynamics of each component of the CERTS microgrid. The static switch has the ability to sense voltage disturbances and to open rapidly to protect the sensitive loads ie to autonomously island the microgrid from disturbances such as faults, IEEE 1547 events, or power quality events. After islanding, the reconnection of the microgrid is achieved autonomously after the tripping event is no longer present. This synchronization is achieved by using the frequency difference between the islanded microgrid and the utility grid. Each source can seamlessly balance the power on the islanded microgrid using real power versus frequency droop and maintain voltage using the reactive power versus voltage droop. The coordination between sources is through frequency and the voltage controller provides local stability. [6]

Microgrid Implementation in Canada Boston Bar – BC Hydro

The Microgrid R&D activities in Canada are focused on development of control and protection strategies for autonomous Microgrid operation at medium voltages. Two of the major utility companies Independent Power Producer (IPP), BC Hydro and Hydro Quebec has implemented microgrid intentional islanding applications. The main objective of planned islanding projects is to reduce sustained power-outage durations and to enhance customer-based power supply reliability on rural feeders by utilizing an appropriately located IPP. Boston Bar town a part of the BC Hydro rural areas is supplied by three 25-kV medium-voltage distribution feeders connected to the BC Hydro high voltage system through 60 km of 69-kV line. The Boston Bar IPP microgrid comprises of two 4.32 MVA run-of-river hydro power generators and is connected to one of the three feeders with a peak load of 3.0 MW, shown in Figure 2.

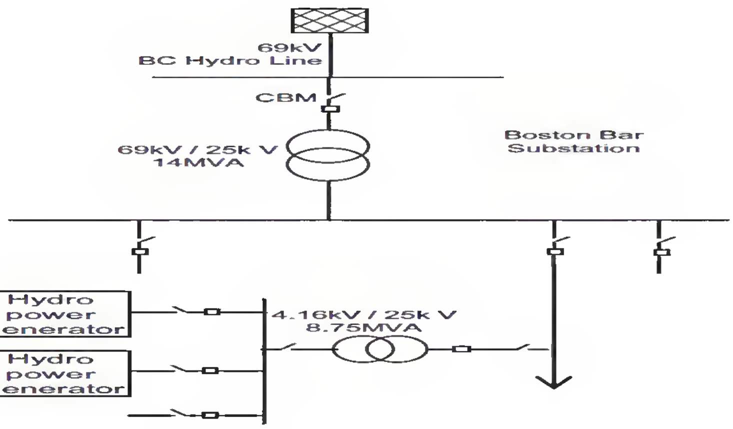

Figure 2: Single-Line Diagram of the BC Hydro Boston Bar System [7]

Depending on the water level, the Boston Bar IPP can supply the community load on one or more of the feeders during the islanding operation. If the water level is not sufficient, the load on one feeder can be sectioned to adequate portions. Based on the BC Hydro islanding guideline, to perform planned islanding, an IPP should be equipped with additional equipment and control systems for voltage regulation, frequency stabilization, and fault protection [7]. Remote auto-synchronization capability was also added at the substation level to synchronize and connect the island area

to the 69-kV feeder without causing load interruption. When a sustain power outage event, such as a permanent fault or line breakdown, occurs on the utility side of the substation, the main circuit breaker and feeder re-closers are opened. Then the substation breaker open position is tele-metered via leased telephone line used for communication between the generators remote control site and the utility Area Control Centre to the IPP operator. Subsequently, the IPP changes the control and protection settings to the island mode and attempts to hold the island downstream of the feeder 2 re-closer. If the IPP fails to sustain the island, the IPP activates a black-start procedure and picks up the dead feeder load under the utility supervision [8]. The planned islanding operation of the Boston Bar IPP has been successfully demonstrated and performed several times during power outages caused by adverse environmental effects. Building on the knowledge and experience gained from this project, BC Hydro has recently completed a second case of planned islanding and is presently assessing a third project.

Microgrid Implementation in Europe

Within the frame of the European Microgrids projects several set-ups have been installed at different laboratories. The first European Union project funded by the EU was the "Microgrids Project" and it was undertaken by a consortium led by National Technical University of Athens (NTUA). The Microgrids project investigated a microgrid central controller (MCC) that promotes technical and economical operation, interfaces with loads and micro sources and demand-side management and provides set points or supervises local control to interruptible loads and micro sources [9]. A pilot installation was installed in Kythnos Island, Greece, that evaluated a variety of DER to create a microgrid. Another project at NTUA is a Laboratory-scale Microgrid Implementation as detailed further.

Microgrid Implementation in Kythnos Island, Greece

The Kythnos island microgrid shown in Figure 3, electrifies 12 houses having load controllers and the generation constitute of 10 kW of PV, a nominal 53 kWh battery bank, and a 5-kW diesel generator set.

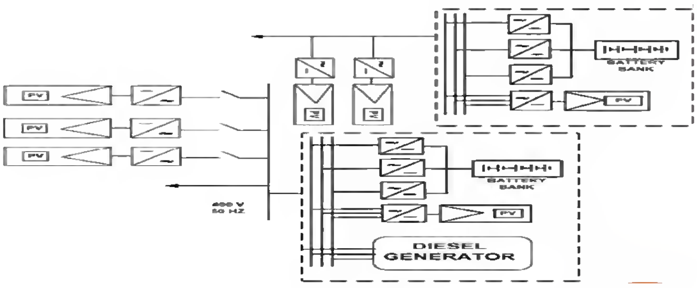

Figure 3: The Kythnos Iisland Microgrid – Greece [11]

A second PV array of about 2 kW, mounted on the roof of the control system building, is connected to an inverter and a 32 kWh battery bank to provide power for monitoring and communication. Residential service is powered by three battery inverters connected in a parallel able to operate in frequency droop mode. When the state of charge of the battery is low, the controllable loads are tripped off thus reducing the consumption, and when the battery bank is approaching full charge, PV inverters are able to sense this and they continuously de-rate the power outputs [10]. Grid frequency is used as communication signal for advanced battery management in addition to the frequency droop concept.

Laboratory-Scale Microgrid Implementation at National Technical University of Athens (NTUA) – Greece

At the international level, the European Union has supported second major research efforts devoted exclusively to

microgrids named “More Microgrid Projects.”: This project was executed to study alternative methods, strategies along with universalization and plug-and-play concepts. The demonstration site is an ecological estate in Mannheim–Wallstadt, Germany [9]. Continuing microgrid projects in Greece include a laboratory facility that has been set up at the National Technical University of Athens (NTUA), a specially designed single phase system of the NTUA with agent control software with the objective to test small-scale equipment and control strategies for microgrid operation. NTUA microgrid test system shown in Figure 4 consist of one wind turbine, two PV generators, storage in battery energy and controllable loads. The battery is connected via a bi-directional PWM voltage source converter, which regulates the voltage and frequency when the system operates in the island mode. The battery inverter operates in voltage control mode (regulating the magnitude and phase/ frequency of its output voltage). When the microgrid operates in parallel to the grid, the inverter follows the grid. Multi-agent technology built on the Java Agent Development Framework (JADe) 3.0 platform has been implemented for the Operation and Control planning of the sources and the loads. The project has been successfully completed providing several innovative technical solutions.

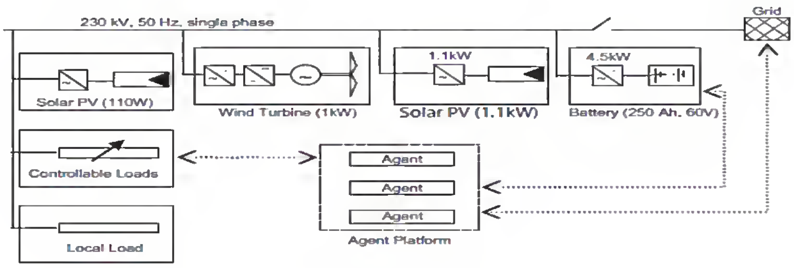

Figure 4: The Laboratory Microgrid Facility at NTUA [10]

Microgrid Implementation in Bronsbergen Holiday Park, Netherlands

In the Netherlands one of the “More Microgrids” projects is located at Bronsbergen Holiday Park, located near Zutphen. The park is electrified by a traditional three-phase 400-V network, which is connected to a 10-kV medium-voltage network via a distribution transformer located on the premises (Figure 5). The distribution transformer does not feed any low-voltage loads outside of the holiday park. Internally in the park, the 400-V supply from the distribution transformer is distributed over four cables, each protected by 200-A fuses on the three phases. It comprises 210 cottages, 108 of which are equipped with grid-connected PV systems of 315 kW catering a peak load of about 90 kW. The objective of this project is experimental validation of islanded microgrids by means of smart storage coupled by a flexible AC distribution system including evaluation of islanded operation, automatic isolation and reconnection, fault level of the microgrid, harmonic voltage distortion, energy management and lifetime optimization of the storage system, and parallel operation of converters [12].

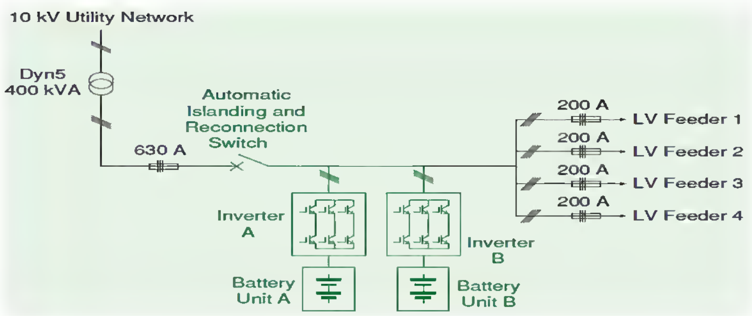

Figure 5: Schematic for the Bronsbergen Holiday Park Microgrid, Netherlands [12]

Microgrid Implementation in DeMoTec – Germany

A comprehensive study on microgrid control methods has been performed in Institut für Solare Energieversorgungstechnik (ISET), Germany. The DeMoTec microgrid at ISET, which is a general test site for DER has a total available generation capacity of 200 kW comprising of a PV generator, a wind generator, two battery units, and two diesel gensets. A number of loads with different priority levels and several automatic switches are there for sectionalizing the microgrid into up to 3 low voltage island grids. A central crossbar switch cabinet connects all generators and loads to a local grid. Figure 6 presents the diagram of the DeMoTec test microgrid.

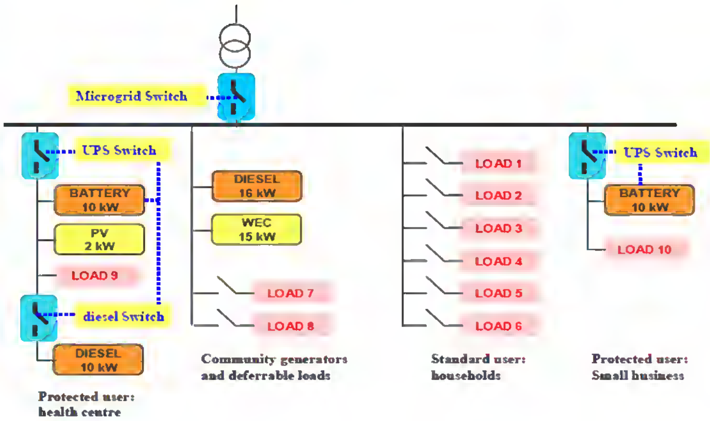

Figure 6: DeMoTec Microgrid Test System [14]

To enable a monitoring and control of the generators and of the operating states of the system A Supervisory Control and Data Acquisition System (SCADA) is deployed. The communication is done via a separate Ethernet communication line and XML-RPC communication protocol is used [13]. The DeMoTec promotes design, development and presentation of systems for the utilization of renewable energies and the rational use of energy. A DeMoTec master display is being used to monitor the operations of a widely dispersed wind power plant system, which comprises about 80 representatively, selected systems throughout Germany. In this master display, moreover, the remote monitoring of remote isolated systems in Greece and Spain as well as the control of active low-voltage grids can also be demonstrated [14].

Residential Microgrid Implementation in Am Steinweg, Stutensee- Germany

A three-phase low voltage (400 V) four-wire small scale test system has been built that is the Residential Microgrid of Am Steinweg in Stutensee –Germany to which 101 apartments are linked. The microgrid which is connected to the medium voltage 20 kV network through a 400 kVA transformer. It consist of a CHP with available electrical power of 28 kW, different PV installations with nominal power of 35 kWp and a lead acid battery bank with a rating of 880 Ah. The battery is connected via a bi-directional inverter of 100 kW.. The maximum active power through the transformer is determined as 150 kW. A schematic diagram of the microgrid is shown in Figure 7. A low voltage grid optimization tool Power Quality Management System that manages grid operation, DG control and demand side management has been employed. The communication medium used in this test system is Transmission Control Protocol and Internet Protocol (TCP/IP), which is the standard for communication in computer networks [15].

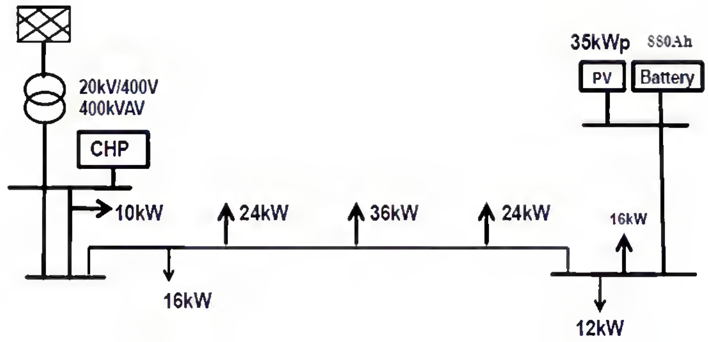

Figure 7: The Residential Microgrid of Am Steinweg in Stutensee Germany [16]

Microgrid Implementation in Cesi Ricerca – Italy

This test system is also comes under "More Microgrids" Projects of the European Union. This is a low voltage 400 VDC microgrid that is connected to the medium voltage 23 kV grids by means of 800 kVA transformer. Figure 8 presents the network configuration of CESI RICERCA DER test microgrid. The communication system is based on wide band power-line carrier technology, and wireless technology that requires a 2.4 GHz radio channel. A pecking order scheme is used to communicate and process information. Optimization techniques are used to schedule the set-points. [17].

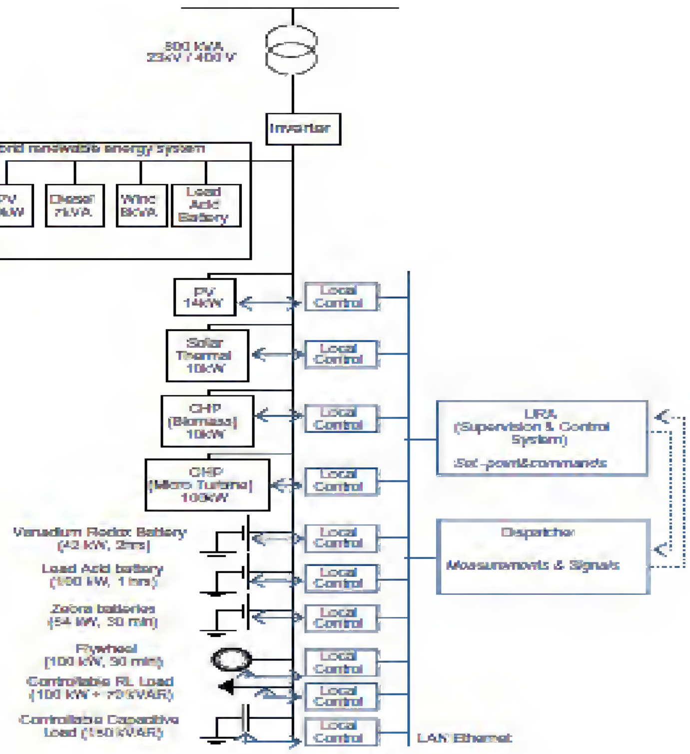

Figure 8: Cesi Ricerca, Italy Test Microgrid Network Configuration [10]

It comprises of the following distributed energy resources and the storage systems:

- A hybrid energy system consisting of a photovoltaic plant (10 kWP), a lead-acid storage, a diesel engine coupled with an asynchronous generator (7 kVA), a simulated (8 kVA) asynchronous wind generator
- Five PV fields of different technologies for a total nominal power of 14 kW

- A solar thermal plant with a parabolic dish and a Stirling engine (10 kW)
- A ORC CHP system fuelled by biomass (10 kWE, 90 kWTH)
- A CCHP plant with a gas microturbine (105 kWE, 170 kWTH, 100 kWRE)
- A Vanadium Redox Battery (42 kW, 2 hours)
- A Lead Acid battery system (100 kW, 1 hour)
- Two high temperature Zebra batteries (64 kW, 30 minutes)
- A high speed flywheel for Power Quality (100 kW, 30 seconds)
- A controllable three-phase resistive-inductive load (100 kW + 70 kVAR)
- A capacitive load and several R/L loads with local control (150 kVAR)

Microgrid Implementation in the University of Manchester, United Kingdom

The hardware topology used in the University of Manchester Microgrid/Flywheel energy storage laboratory prototype is shown in Figure 8. The overall microgrid test system is nominally rated at a 20kVA, although the flywheel and power electronics are rated much higher 100kW connected with 0.4 kV mains supply of the laboratory considered as the

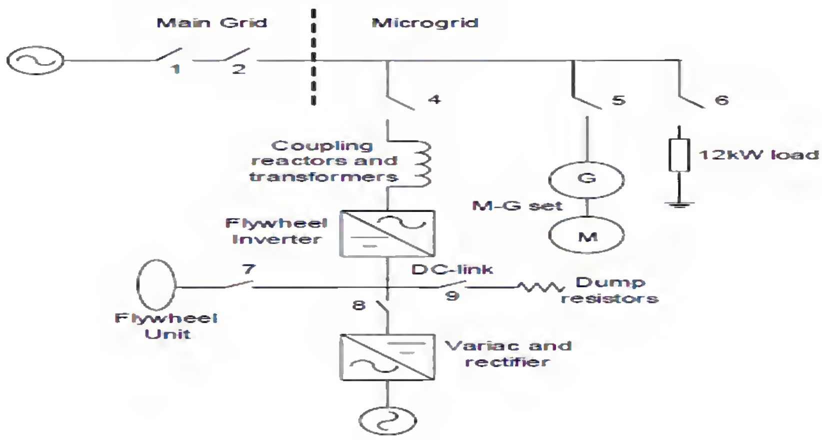

Figure 9: MicroGrid Layout Schematic at Manchester [18]

main grid. A synchronous generator and an induction motor coupled together acts as the micro-source. A three-phase balanced load of 12 kW is connected at the end of the feeder. Control systems for real time control of the Microgrid hardware, using the Simulink/ dSPACE control environment has been developed in 2005. The test-rig has been designed to allow the investigation of power-electronic interfaces for generation, loads or energy storage. The AC/DC inverter labelled 'flywheel inverter' can be configured in software to allow the interfacing of the flywheel storage system to the remaining microgrid unit. The Microgrid may be operated in islanded operation. Breaker 1 is opened to emulate a loss of mains condition as shown in the Figure 9. Breaker 2 is under the control of the Microgrid controller system. Thus the onset of islanding, and resynchronization to mains, as well as mains connected operation may be tested [18].

CHALLENGES IN MICROGRID SYSTEMS

Benefits of microgrids most often chosen are to meet local demand, to enhance grid reliability, and to ensure local

control of supply. As microgrids contain the technology from distributed generation and storage, the challenges from these two technologies are more or less as it is transferable to microgrids.

A general challenge remain on how to run every component in MG systems at its optimal operating condition and to improve their capability to fault ride-through during grid disturbances. Other main point to be taken care of is the Control strategies must move towards decentralization to achieve the plug and play of micro grids in a better efficient manner. Enabling technologies energy management systems, distribution management systems, and sensors have much scope for better advancements.

Another issue is related to information and communication infrastructures which are like the nervous system of any network. In order to make the low voltage electricity grids intelligent the application of Information & Communication Technology (ICT), remote sensing and communication technology to power systems must gain momentum making Micro-Grids smart.

The need for standards is more important for developing microgrids when compared to distributed generation and energy storage. The thriving interest on standardization of microgrids is reflected by the forthcoming IEEE Standard P1547.4 on Guide for Design, Operation and Integration of Distributed Resource Island Systems with Electric Power Systems [19] which is specifically developed to address the missing information in IEEE Standard 1547-2008 [20] regarding intentional islands.

In the long-run, as energy storage and renewable energy manufacturing prices decrease, we see global deployments increasing three-to four-fold. Yet, there are still many research and development needs to be associated with the microgrids.

CONCLUSIONS

Microgrids have been proven capable of coordinating and managing Distributed Resource to provide their full benefits in a more decentralized way thus reducing the need for the centralized coordination and management of such systems. The Microgrid capability has been overwhelmingly developed by and for applications in highly developed economies; however, the existence of microgrid technology might also alter the trajectory of progress in less-developed economies. It is interesting to discover that microgrids persist playing potential role in a global emerging smart electrical energy future as the microgrid technology demonstration projects move toward commercial developments in diverse future applications,

Although across the globe several microgrid projects have been productively implemented in the advanced countries and few are in progress in the developing countries too, the process is expected to take a good pace with more emphasis on the smart grid to be factual. This paper has presented a detailed appraisal of the succesful development and implementation work functional in North America at United States & Canada, in Europe at Germany, Italy, UK. This swot gives an insight into some practical challenges being encountered for establishing and operating the microgrids sites. European Union leads the world in utilizing distributed generation and adopting microgrids, whereas North America is prominent in energy storage technology. These two regions view the advanced electric grid as a gateway to innovation, energy independence, and economic security. These are the global region those will continue witnessing the most growth in microgrids over the coming years.

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